

In-flight performances of SilEye-2 Experiment and cosmic ray abundances inside space station Mir.

V Bidoli†, M Casolino†††, E De Grandis†, M P De Pascale†, G Furano†, A Morselli†, L Narici†, P Picozza†, E Reali†, R Sparvoli†, A Galper‡, A Khodarovich‡, M Korotkov‡, A Popov‡, N Vavilov‡, G Mazzenga§, M Ricci§, G Castellini||, S Avdeev¶, M Boezio⁺, W Bonvicini⁺, A Vacchi⁺, N Zampa⁺, P Papini*, P Spillantini*, P Carlson‡ and C Fuglesang§§.

† INFN ROMA2 and University of Roma Tor Vergata, Italy

‡ Moscow Engineering and Physics Institute, Moscow, Russia

§ LNF - INFN, Frascati (Rome), Italy

|| IROE of CNR, Florence, Italy

¶ Russian Space Corporation "Energia", Korolev, Moscow region, Russia

⁺ University of Trieste and INFN Sezione Trieste, Italy.

* University of Firenze and INFN Sezione Firenze, Italy

‡ Royal Institute of technology, Stockholm, Sweden

§§ European Astronaut Centre, ESA, Cologne, Germany.

E-mail: casolino@roma2.infn.it

Abstract. Cosmic ray measurements performed with the instrument SilEye-2 on Mir space station are presented. SilEye-2 is a silicon detector telescope for the study of the causes of Light Flashes perception by astronauts. As a stand-alone device, it monitors in the short and long term the radiation composition inside Mir. The cosmic ray detector consists of an array of 6 active silicon strip detectors which allow nuclear identification of cosmic rays up to Iron. The device was operational for more than 1000 hours in the years 1998-2000, measuring also several Solar Particle Events. In this work we present the in-flight performance of the instrument and nuclear abundance data from Boron to Silicon above $\simeq 150$ MeV/n inside Mir.

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†† Corresponding author: Dept. of Physics - University of Roma Tor Vergata, Via della Ricerca Scientifica 1 - 00133 Roma, ITALIA

1. Introduction

A detailed study and understanding of the radiation environment in space and its effects on human physiology has a growing importance in light of work on the International Space Station (ISS) and of a future mission to Mars. Radiation in orbit comes from cosmic rays of different energies and origins. In addition to the galactic component - which is modulated by the solar activity at low energies - there are also solar energetic particles associated with transient phenomena such as solar flares and coronal mass ejections. Inside Earth's magnetosphere there is also the significant contribution of trapped particles: to the well-known proton and electron belts, recent studies have shown a more complex nuclear composition, for instance, with trapped components of anomalous cosmic rays [1]. For Low Earth Orbits such as those of Mir, ISS or Shuttle (altitude of 300-400 km, inclination of 51.6°) the effect of trapped radiation is most evident in the South Atlantic Anomaly (SAA). This is a region located between South America and Africa where the geomagnetic field is lower and particle flux increases. It is also important to study $Z > 1$ cosmic ray component for its high quality factor which - even with a low flux - can give a non-negligible contribution to the dose absorbed by astronauts.

In addition to the effects of radiation, there are also other processes that need to be studied in order to have a more complete knowledge of the human response to space environment. One of these phenomena is the "Light Flashes" (LF) effect, originally predicted in [2, 3] and reported for the first time in 1969 by the Apollo-11 mission to the Moon. Subsequently, LF were observed by astronauts in the Apollo, Skylab, Shuttle and Mir missions [4, 5, 7]. The SilEye- 1 and 2 experiments were designed to study this phenomenon and the radiation environment on board Space Station Mir. In order to correlate LF observations by the cosmonaut with cosmic rays it is necessary to measure charge, energy deposition and direction of the incoming particles in real time. The use of active silicon detectors [8, 9] is necessary to meet these requirements with the limitations of mass, size and power consumption. SilEye-1 was operational on Mir between December 1995 and December 1997[10, 11]. It performed the first LF observations on Mir and carried the prototype of the silicon detector. SilEye-2[12, 13] was first turned on in August 1998 with systematic observations starting in October 1998. It was operational in various periods until August, 28, 1999. When the last crew reached Mir in March 2000, SilEye-2 was used again during the mission (until June 2000).

In this work we discuss the in-flight performances of the detector and particle composition on board space station Mir using data gathered between August 1998 and August 1999. This data set consists of 93 sessions, 17 of which were devoted to Light Flashes observations. More than 10^7 particle events have been acquired in 1068 hours of observation time: during these observations 7 Solar Particle Events (SPEs) were also detected. The latest data set (year 2000) is currently under analysis. LF results are presented in [14].

2. The experimental device

SilEye-2 consists of a silicon detector telescope, shown in Figure 1, housed in an aluminum box, coupled to an "helmet" with an eye mask, and worn by the cosmonaut. The device is connected to a laptop computer equipped with a data acquisition card and a joystick. The detector is small (maximum dimension: 26.4 cm, mass 5.5 kg),

robust and easy to handle. A computer based control software performs data handling and storage. To carry out LF observations, the astronaut wears the helmet which holds the detector box and presses the joystick button when he observes LF. Data come, therefore, from two independent sources: the particle track recorded by the silicon detector and the observation of the LF by the astronaut. The helmet has a mask that shields the astronaut's eyes from light; three internal LEDs allow to cross-check the correct position of the detector, verify the dark adaptation of the observer and measure his reaction time to normalize measurements performed by different astronauts.

The device can also be operated as a stand-alone cosmic ray detector without the presence of the cosmonaut; in this acquisition mode a monitoring of the environmental radiation inside Mir is performed. Each event (cosmic ray or LF observation) has a time stamp (50 ms precision) to correlate it with the orbital position of Mir. A particle event is defined by the energetic and topological information coming from the strips hit by incoming particle(s); an LF event consists of the time of clicking the joystick button.

The particle detector telescope is made of a series of six silicon active wafer, originally developed in the construction of NINA-1 and 2 cosmic ray space telescopes [15, 16]. The device structure is shown in Figure 2. The detector is positioned on the temple of the cosmonaut in order to cover the maximum angle for cosmic rays impinging on the eye. In stand-alone mode for cosmic ray measurements it is placed on a in a specific location on Mir. The position of the device is recorded each session in order to reconstruct its orientation in respect to the station. Each of the six silicon wafers has an active area of $60 \times 60 \text{ mm}^2$, divided in 16 strips 3.6 mm wide; the thickness is $380 \pm 15 \mu\text{m}$. Two wafers, orthogonally glued back to back, constitute a plane. Three planes are used together, for a total number of 96 strips and an active thickness of 2.28 mm. The distance between the silicon planes is 15 mm; the geometrical factor is $85 \text{ cm}^2 \text{ sr}$ if particles hitting the detector from both sides are considered. The silicon strips are depleted by a DC voltage of 36 V, supplied by batteries insulated from the rest of the circuit board. The outermost strips of plane 1 (1 and 16) are disconnected while those of planes 2 and 3 are connected to the same readout channel. The readout channels saved in this way are used for housekeeping information. Among the housekeeping values are the inverse currents of each silicon plane. In addition, there are two Analog Low Rate Meters (which measure incident rate on plane 1, view X and Y, up to 400 Hz) and three Analog High Rate Meters (one per plane) which measure particle rate up to 20 kHz. We therefore have 88 physics and 8 housekeeping channels for a total of 96 readouts per event.

Two passive absorbers (1 mm iron each) are inserted between the position-sensitive planes to extend the energy range. For single track events, the particle trajectory is determined with an angular accuracy of 5 degrees. Each analog signal comes into the Read-out board, which performs the tasks of Analog-to-Digital Conversion (ADC), trigger and calibration. For each trigger, data are converted by a 12 bit ADC and sent to FIFO (First in, first out) for acquisition by the read out card. The ADC has a dynamic range up to 12.2 pC of injected charge: thus SilEye-2 can measure particle energy losses per strip from 0.25 MeV ($0.69 \text{ keV}/\mu\text{m}$) to about 300 MeV ($830 \text{ keV}/\mu\text{m}$) and then determine nuclear species. The analogic sum of the signals from the strips of each view is used as a input for the trigger system, performed by a PAL (Programmable Array Logic) unit mounted on the Read-out board. Denoting X_i and Y_i the views of the plane i and P_i the analogic OR ($P_i = P_{i,x} + P_{i,y}$) of the

two views x and y of Plane i , we have the following main trigger:

$$((X_1 \text{ AND } P_3) \text{ AND } (Y_1 \text{ OR } P_2)) \quad (1)$$

The threshold is set at $0.69 \text{ keV}/\mu\text{m}$. Particles are therefore required to cross the detector in order to have a trigger to read the event. The minimum energy to have a trigger - determined with Montecarlo simulations - is shown in Table 1. The $0.69 \text{ keV}/\mu\text{m}$ trigger threshold, necessary to optimize the detector for high Z nuclei observation (of higher interest for LF), reduces proton detection efficiency at high energies (above 100-200 MeV). As energy increases the energy deposited decreases and reduces trigger probability: above 400 MeV the efficiency is $\simeq 7\%$. Particles from both sides of the detector are read: however the material crossed is different in the two cases, since particles cross the 0.2 mm Cu window on one side (closer to the cosmonaut's head) and $\simeq 2$ cm of electronics on the other. This requires a correction in the energetic spectrum of low energy particles coming from this direction, but - aside from nuclear fragmentation in the interposed material - does not appreciably affect nuclear composition.

Data from the FIFO are then sent - through an interface board - to a PCMCIA Digital Acquisition Board housed in the laptop. The interface board also handles data coming from the cosmonaut joystick and the LEDs used for eye adaptation. The acquisition software includes a data quick-look to be performed by the cosmonaut who can also add personal comments after the conclusion of each session. Data storage is performed on PCMCIA hard disks; data transfer to Earth is performed by the crew who brings the hard disks to Earth when returning from Mir.

3. DATA ANALYSIS

The study of the radiation environment on board manned spacecrafts allows evaluation of the dose absorbed by the astronauts in order to assess the risks involved in space missions. The complexity of the information required for a detailed comprehension of the radiation environment grew with the improvement of the detectors and the understanding of the near Earth and interplanetary radiation environment. The use of active detectors allows a measurement in real time of the nature of charged radiation impinging on the spacecraft and the modifications of the cosmic ray flux due to the interaction with the material of the spacecraft itself. These studies have to be carried forth both in solar quiet and active conditions, in order to take into account the dose absorbed by astronauts during SPEs. The time and intensity variability of these events make them real threats to long term activities outside the geomagnetic shielding such as a mission to Mars[17]. In this work we analyse the performance of the silicon detector and report on cosmic ray measurements.

3.1. Calibration

Each acquisition session begins with the calibration of the detector. The position and RMS (Root Mean Squared) of the electronic pedestal of each silicon strip is evaluated with 1024 measurements. Figure 3 shows the histograms of average and RMS values of the detector strips. The thin line refers to one of the first acquisition sessions (14/02/98), while the thick line refers to one of the last (31/07/99). Notice how the position of the pedestal has remained constant during work. In addition, the noise of the pedestal has decreased (the RMS of 7 ADC channels during the first session

decreases to 4-5 channels in the 1999 sessions), proving the stability of the electronics and the absence of measurable detector degradation. Plane 1 has a lower pedestal offset than planes 2 and 3. This results in a double peaked structure in the average value with lower pedestal values due to plane 1 and higher values to planes 2 and 3. It is also to be noted that noise measurements on board Mir are lower than those obtained during ground tests, probably due to a more stable power source. After the calibration - which lasts about 3 minutes - data acquisition begins. For each trigger, data are converted and pedestal suppression is performed, keeping only the information from those strips which show an energy release above 3 RMS from the calculated pedestal.

3.2. Detector response and linearity

Particle flux in Low Earth Orbit basically depends on two parameters: the geomagnetic shielding and solar activity. The former is higher at the geomagnetic equator and thus results in a lower flux. At higher latitudes the shielding is lower and particle flux increases. Another cause of increase is related to SPEs caused by Coronal Mass Ejections or solar flares.

The space station Mir has a 51.6° inclination orbit and an altitude varying between 300 and 400 km. Particle flux on board Mir varies along the orbit according to the geomagnetic latitude and passage in the South Atlantic Anomaly (SAA), where particle flux increases considerably due to the presence of trapped protons. Figure 4 shows a typical radiation acquisition session with SilEye-2 detector: a plot of the number of events as a function of time displays the oscillatory behaviour typical of the passage between high and low latitude regions. The highest peaks are present during passage in the SAA where particle rate increases with an order of magnitude. The middle curve shows the rate of $Z \leq 4$ particles (mostly protons). The lower curve shows the rate of $Z > 4$ nuclei: this component does not increase in the SAA as much as proton and helium. The high latitude and SAA flux increase is more evident if plotted as function of position, as shown in Figure 5.

Detector response to incoming particles can be divided in two broad categories: below and above $\simeq 100 \text{ MeV}/n$. In the former case, energy release increases as the particle crosses the planes. Above $\simeq 100 \text{ MeV}/n$ energy release can be assumed constant with differences due to energy loss fluctuations in each plane. Particles belonging to this interval can be selected if the energy release between the first and last plane does not differ more than 20%. The E_{con} column of Table 1 shows the threshold energy for different nuclei selected with this cut. The calibration of the device is performed with the aid of Montecarlo simulations using Geant 3.21 software for the energy loss calculation in the detector for all nuclei involved and cross-checked with SRIM[18], a program devoted specifically to the calculation of ion energy loss in matter. With the additional requirement of selecting single particle events, nuclei can be identified according to their total energy released in the detector as shown in Figure 6. In addition to the large proton and helium contribution (not separated with this approach), abundant nuclear species such as Boron, Carbon, Nitrogen etc. up to Iron can be distinguished. The probability distribution of the energy release by a particle in a thin absorber is described by a Landau distribution:

$$f(\lambda) = \int_0^\infty u^{-u} \cdot e^{-u \cdot \lambda} \sin(\pi u) du \quad (2)$$

In order to extract calibration and nuclear abundance information, nuclear peaks have been fitted with a Landau distributions per nucleus. The fit has considered the nuclei from B to Si (10 distributions for 10 nuclei). Each distribution can be characterized with three free parameters P_i according to the following equation:

$$f(\lambda) = P_1 \cdot \int_0^\infty u^{-u} \cdot e^{-u \cdot P_2(\lambda - P_3)} \sin(\pi u) du \quad (3)$$

with: P_1 proportional to the height, P_2 to the width and P_3 to the position of each nuclear distribution. The fit uses 32 free parameters: 30 for the 10 Landau distributions and 2 for an exponential tail used to estimate the $Z < 4$ contamination over B and C. With this approach it is possible to take into account reciprocal contamination of different nuclei; the good agreement of data with the fit, with a normalized $\chi^2 = 3.1$ proves the excellent behavior of the detector. Subsequently we performed a linear fit of the values of P_3 (in ADC channels) of each nuclear species, corresponding to the peak of the distributions (the most probable energy release) as a function of the square of the charge of the incident particle. The correlation coefficient of $R = 1$ shows the good detector linearity. A fit of the correlation between the theoretical energy loss (evaluated with Montecarlo) and the measured ADC values is used to determine the conversion factor of the detector: this is equal to 13.56 channels/MeV, corresponding to an ADC resolution of 74 keV/channel (with $R = 0.9996$).

3.3. Nuclear Abundances

From the fit of the Landau curves it is possible to derive the nuclear relative abundances inside Mir in different positions and solar activity conditions. In this case we have considered solar quiet days in order to provide a reference to subsequent analysis of Solar Particle Events. We have divided the data set according to the McIlwain parameter L and the geomagnetic field B in three regions: Galactic Cosmic Ray region (GCR, $L > 2$), South Atlantic Anomaly (SAA, $L < 2$ and geomagnetic field $B < 0.25\text{G}$), and the remaining region ($L < 2$, $B \geq 0.25\text{ G}$). The McIlwain parameter L represents - at a first approximation - the value (expressed in Earth radii) at which the magnetic field line passing through the point considered intersects the geomagnetic equator. In case of low earth orbits (such as Mir) values close to $L = 1$ are in proximity to the equator and increase at higher latitudes. For a detailed definition see [6]. This reference system is particularly useful since charged particles spiral along the magnetic field and bounce between the mirror points at values of constant L . In a given point of the orbit, the geomagnetic cutoff C determines the minimum energy for primary cosmic rays to reach Mir and to be detected by SilEye. Note that this value is valid for particles orthogonal to the local field line and outside Mir. In addition, particle energy inside the station can be modified by the interposed material of the station and the presence of nuclear interactions, so it should be used only as a reference. Particles with energy equal or lower to the energies shown in the E_{abs} column of Table 1 are absorbed by the 3mm Al material of the external hull of the station. The E_{min} column of Table 1 shows the minimum kinetic energy necessary for trigger (after passage through the hull of the Mir). This implies that a 50 MeV/n carbon nucleus would have the energy to cross (in orthogonal incidence conditions) the hull of the station but could not give a trigger in the detector: in this experiment the minimum trigger energy for carbon is 90 MeV/n, of which 20 MeV/n are lost in

the Al of the station. Naturally the 3mm Al thickness assumed only represents a lower value, since the station and the equipment contained can be interposed between the detector and the local field line along which the particles come.

At $L = 2$, $C = 3.9 \text{ GV}$ while at high latitude ($L=4.4$) $C = 0.8 \text{ GV}$. These two values represent the minimum cutoff for a given region; they correspond to a minimum kinetic energy (for particle with mass/charge ratio of 2) of $\simeq 150 \text{ MeV/n}$ ($C = 0.8 \text{ GV}$) and $\simeq 1600 \text{ MeV/n}$ ($C = 3.9 \text{ GV}$). Particles have been selected with the same cut described in the previous subsection. At this energies particles lose only a small fraction of their kinetic energy in crossing the hull of the station: again, using 3 mm of Al as a reference, we find that, for instance, a 150 (1600) MeV H loses 3.4 (1.3) MeV to enter the station. In case of other nuclei, the values are similar: if we consider carbon, we have 4.8 (1.2) MeV lost for 150 (1600) MeV/n. The particle distributions of the three regions are shown in Figure 7. The continuous line shows the galactic component, which has an higher flux due to the lower geomagnetic cutoff. This allows particles with lower energy to reach Mir and be detected by SilEye resulting in a higher particle count. The wider energy range implies a larger energy release range, resulting in the peaks to be less sharply defined. In this range, proton and helium flux is lower than that measured in the SAA (dotted line) where the trapped component is dominant if compared to galactic and $L < 2$ abundances. Indeed the $L < 2$ curve (dashed) has a lower $Z \leq 2$ flux if compared to SAA but an equal $Z \geq 5$ flux, since in both cases the component selected at this energy is the same. From these distributions it is possible to reconstruct relative abundances and absolute integral fluxes for the different nuclear species (shown respectively in Table 2 and 3). Thus absolute fluxes represent an average above the regions where the geomagnetic cutoff is higher than the minimum values of 3.9 and 0.8 GV and can be as high as 16 GV. Determination of the proton spectrum requires detailed corrections for the energy dependent trigger efficiency so we currently present only $Z > 4$ results (where trigger efficiency can be assumed equal to 1). Table 2 also shows the relative cosmic ray abundances at 1AU[21] measured in the energy range of $\simeq 1 \text{ GeV}$. It is possible to see how, especially for the $L < 2$ regions, notwithstanding the bulk of the Mir, the data are in general in agreement. There are, however, the following notable differences:

- An overabundance of B in respect to C. It is roughly twice the 1AU value in all three regions. This could be accounted as secondary production due to hadronic interactions.
- A higher amount of N in the $L > 2$ region compared to the other regions and 1AU data. This could be due to an larger production of secondary N at lower energies.
- A lower amount of Oxygen nuclei in $L > 2$ and $L < 2$ regions (SAA value is in agreement within errors with 1 AU data). Also in this case the effect can be explained with an higher hadronic interaction cross section for O in respect to C: Oxygen could be considered as composed of four alpha particles (He nuclei) and Carbon of three. Thus, if we assume the ratio of the cross sections to be equal of the ratio of the nucleons of Carbon and Oxygen ($12/16 = 0.75$) and we multiply by the original flux of 0.93 we obtain an abundance of 0.7.
- An higher amount of Ne and lower amount of Mg and SI in the $L > 2$ region.

In all cases it is clear that a crucial role is played by hadronic interactions in the matter, but an accurate estimate of the processes involved is complicated by

the estimation of the energy-dependent cross sections and the amount of material interposed between SilEye and the exterior of the station. Given the conditions of this measure, the agreement with 1AU data is rather good: the larger differences occur in the $L > 2$ region, where cutoff is lower and particles have a wider energy range. To improve the measure of cosmic ray abundances inside Mir it will be necessary to separate sessions and incident angles in order to obtain a clearer sample of cosmic rays.

3.4. Linear Energy Transfer

The LET in silicon measured with SilEye-2 is shown in Figure 8: in this work we present solar quiet period data for the three geomagnetic regions described in the previous section. The LET is obtained normalizing the total energy release to the angle of incidence for single and multiple track events. The topmost curve shows the SAA, where trapped protons are the dominant contribution; the galactic nuclear flux (middle curve) is dominant at LET above $8 \text{ keV}/\mu\text{m}$. The bottom curve represents LET at $L < 2$ and outside the SAA: the proton component is below the previous two regions, and the high LET component is - as expected - equal to the SAA region. In these two regions the nuclear component is lower than in the $L > 2$ zone due to the higher geomagnetic cutoff. As previously mentioned, trigger efficiency for protons (which constitute the peak at $1 \text{ keV}/\mu\text{m}$) varies according to incident energy: a detailed Montecarlo simulation, currently in progress, is thus required to reconstruct the original proton spectrum, in order to derive - from the measured LET - the dose absorbed by the cosmonauts. The different nuclear abundances and fluxes result in different LETs and therefore different doses absorbed by the astronauts. If we evaluate the dose absorbed in silicon (considering the component above $1 \text{ keV}/\mu\text{m}$) from the LET of a typical session (20/10/98) we obtain $103 \pm 10 \mu\text{Gy}/\text{day}$ in the high latitude region, $271 \pm 15 \mu\text{Gy}/\text{day}$ in the SAA and $34 \pm 3 \mu\text{Gy}/\text{day}$ in the remaining region. GCR values are lower than those presented in [22] of $146.74 \mu\text{Gy}/\text{day}$ (GCR) and in [9] of $172.8 \mu\text{Gy}/\text{day}$. However, in the previous experiments the instrument sensitivity extended below the SilEye limit of $1 \text{ keV}/\mu$. In addition, in [22] a tissue equivalent proportional counter is used so that the LET in water is measured. In [9] the measurement is made in silicon and the relation $LET_{\infty} = 1.193 \times LET_{\text{silicon}}$ (where LET_{∞} is the LET in water) is used. If we consider the SAA, the value presented by [22] is $233.31 \mu\text{Gy}/\text{day}$, in good agreement with our measurement although they are lower than the value of $6912 \mu\text{Gy}/\text{day}$ of [9] due to the increased flux of high energy trapped protons which release less than $1 \text{ keV}/\mu\text{m}$. In all cases we find in the SAA (as expected) the highest absorbed dose due to the presence of trapped protons. The equivalent dose, however, is at the maximum in the $L > 2$ region where cutoff is lowest and $Z > 5$ particle flux is higher: the dose equivalent (ICRP-1990) values are $840 \pm 50 \mu\text{Sv}/\text{day}$ in the $L > 2$ region, $600 \pm 40 \mu\text{Sv}/\text{day}$ in the SAA and $250 \pm 20 \mu\text{Sv}/\text{day}$ in the remaining low latitude region.

4. Conclusions

In this work we have presented the in-flight performance of the SilEye-2 detector and its first observational results. The good behaviour of the detector and its particle identification capabilities enable the study of the cosmic ray and radiation environment and its short- and long-term temporal variations. Analysis is currently in progress to

determine relative abundances and fluxes in these conditions and in presence of Solar Particle Events and to improve the identification capabilities of the device for low Z nuclei and at lower energies. Linear Energy Transfer measurements will be as well used to characterize the radiation environment on board Mir space station in solar quiet and active days.

Development is planned for a future detector with the construction of two new devices to continue and extend the observational capabilities of SilEye-2 on the International Space Station: Sileye-3/Alteino. This detector, to be launched in 2002, is similar in size ($8 \text{ wafers each } 8 \times 8 \text{ cm}^2$) to Sileye-2 and, in addition to new electronics and detectors, will also carry an electroencephalograph to perform a real time correlation between Light Flash perceptions by astronauts and cosmic rays. The technology developed for SilEye-3 will be used in the construction of a larger facility, originally proposed in [19] and evolved in the Altea (SilEye-4) project[20], currently under development.

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Table 1. Left: Threshold energy for absorption in 3mm Al of the hull of Mir (E_{abs}); Center: Threshold energy (after entrance in the Mir) for trigger (E_{min}); Right: Threshold energy for constant energy loss in the detector (E_{con}) (see text).

Z	E_{abs} (MeV/n)	E_{min} (MeV/n)	E_{con} (3mm Al) (MeV/n)
1 H	24	30	60
2 He	24	37	65
3 Li	28	40	75
4 Be	34	50	90
5 B	39	50	105
6 C	45	70	115
7 N	49	65	125
8 O	53	80	140
9 F	55	80	145
10 Ne	60	90	150
11 Na	61	95	155
12 Mg	66	100	165
14 Si	71	110	185
18 S	77	120	200
20 Ca	88	140	230
26 Fe	98	150	250

Table 2. Relative abundances normalized to carbon in the three regions for particle with $E > E_{con}$ (see text).

Z	$L > 2$ ($C > 0.6 \text{ GV}$)	$L \leq 2$ ($C > 3.9 \text{ GV}$)	SAA ($C > 3.9 \text{ GV}$)	600-1000 MeV/n [21]
5 (B)	0.63 ± 0.09	0.53 ± 0.35	0.55 ± 0.09	0.307 ± 0.005
6 (C)	1 ± 0.1	1 ± 0.06	1 ± 0.12	1 ± 0.02
7 (N)	0.41 ± 0.06	0.34 ± 0.08	0.22 ± 0.04	0.274 ± 0.007
8 (O)	0.65 ± 0.07	0.66 ± 0.08	0.77 ± 0.17	0.93 ± 0.02
10 (Ne)	0.33 ± 0.06	0.13 ± 0.02	0.12 ± 0.02	0.149 ± 0.004
12 (Mg)	0.07 ± 0.02	0.13 ± 0.02	0.12 ± 0.02	0.187 ± 0.005
14 (Si)	0.05 ± 0.02	0.1 ± 0.02	0.1 ± 0.02	0.13158 ± 0.00003

Table 3. Integral fluxes measured in the three regions above for particles with $E > E_{con}$ of Table 1.

Z	$L > 2$ ($C > 0.6 \text{ GV}$) $part/(cm^2 \text{ sr s})$	$L \leq 2$ ($C > 3.9 \text{ GV}$) $part/(cm^2 \text{ sr s})$	SAA ($C > 3.9 \text{ GV}$) $part/(cm^2 \text{ sr s})$
5 (B)	$(6.6 \pm 0.6) \times 10^{-5}$	$(1.6 \pm 1) \times 10^{-5}$	$(1.5 \pm 0.2) \times 10^{-5}$
6 (C)	$(10.5 \pm 0.5) \times 10^{-5}$	$(3.0 \pm 0.1) \times 10^{-5}$	$(2.6 \pm 0.2) \times 10^{-5}$
7 (N)	$(4.3 \pm 0.5) \times 10^{-5}$	$(1.0 \pm 0.2) \times 10^{-5}$	$(0.59 \pm 0.08) \times 10^{-5}$
8 (O)	$(6.8 \pm 0.4) \times 10^{-5}$	$(2.0 \pm 0.2) \times 10^{-5}$	$(2.0 \pm 0.3) \times 10^{-5}$
10 (Ne)	$(3.5 \pm 0.5) \times 10^{-5}$	$(0.38 \pm 0.03) \times 10^{-5}$	$(0.31 \pm 0.06) \times 10^{-5}$
12 (Mg)	$(0.7 \pm 0.2) \times 10^{-5}$	$(0.39 \pm 0.05) \times 10^{-5}$	$(0.33 \pm 0.06) \times 10^{-5}$
14 (Si)	$(0.5 \pm 0.2) \times 10^{-5}$	$(0.29 \pm 0.15) \times 10^{-5}$	$(0.26 \pm 0.05) \times 10^{-5}$

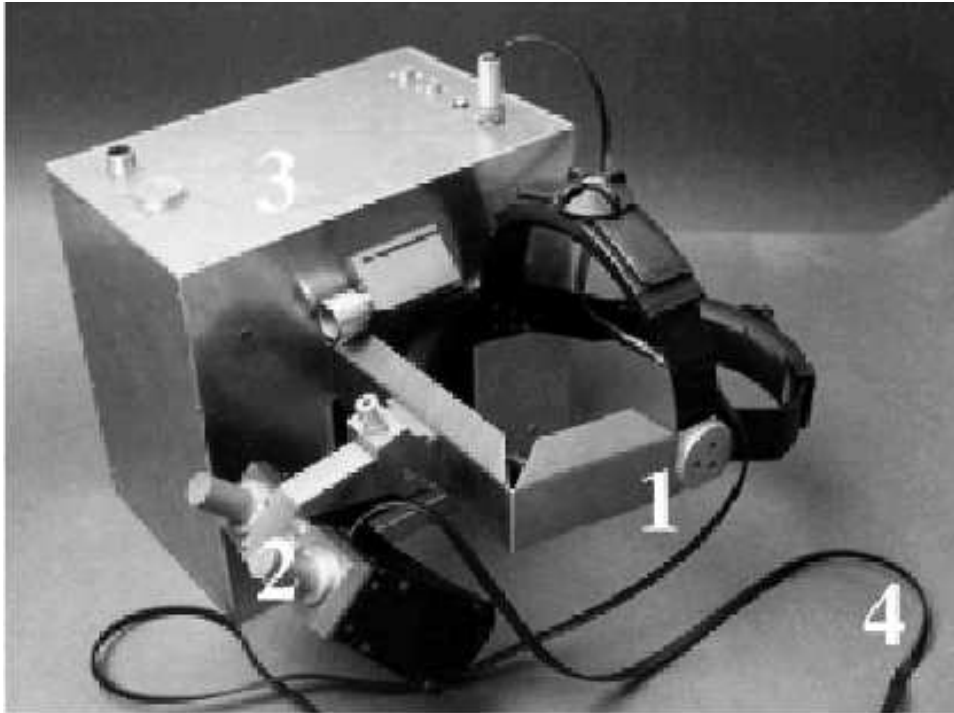


Figure 1. Photo of the SilEye-2 helmet and detector case: 1. Head Mounting. 2. Eye mask with internal LEDs. 3. Detector Box. 4. Connection cable for the LEDs used for dark adaptation tests .

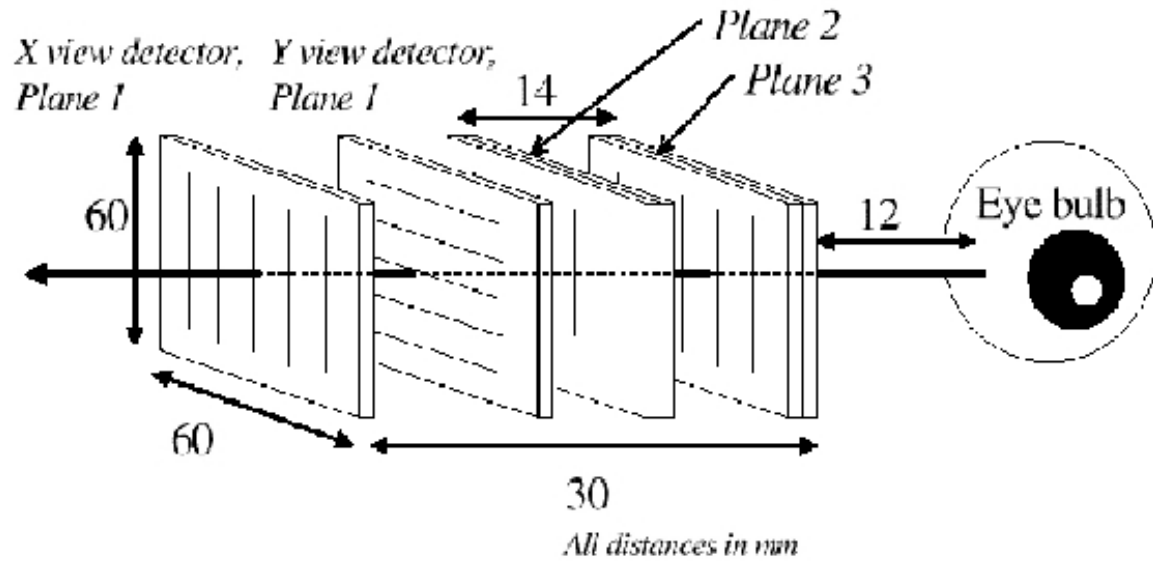


Figure 2. Scheme of the SilEye-2 silicon detector: six 16 strip silicon layers glued in pairs with strip orthogonally aligned form three planes (the two layers of the first plane are drawn separately). The position of the eye bulb is also shown.

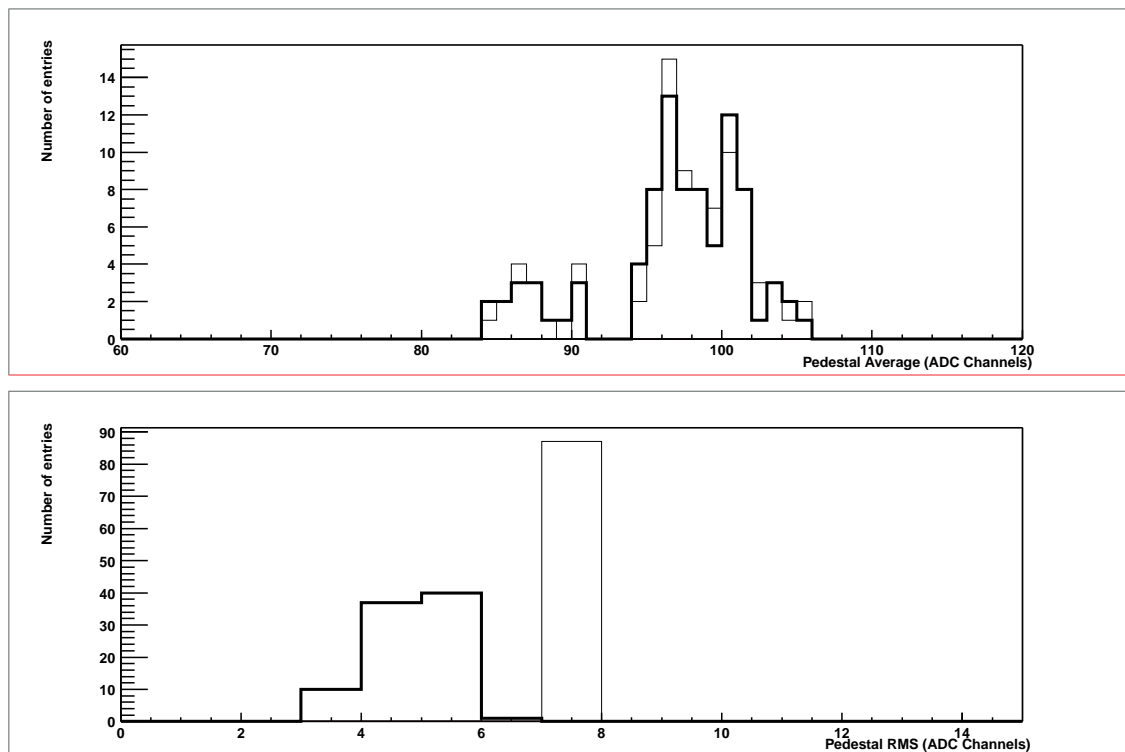


Figure 3. Top: Histogram of the average value of the electronic pedestals of each detector strip. The data refers to the sessions of 14/02/98 (thin line) and 31/07/99 (thick line). Bottom: Histogram of the RMS value of the electronic pedestals for the sessions of 14/02/98 (thin line) and 31/07/99 (thick line).

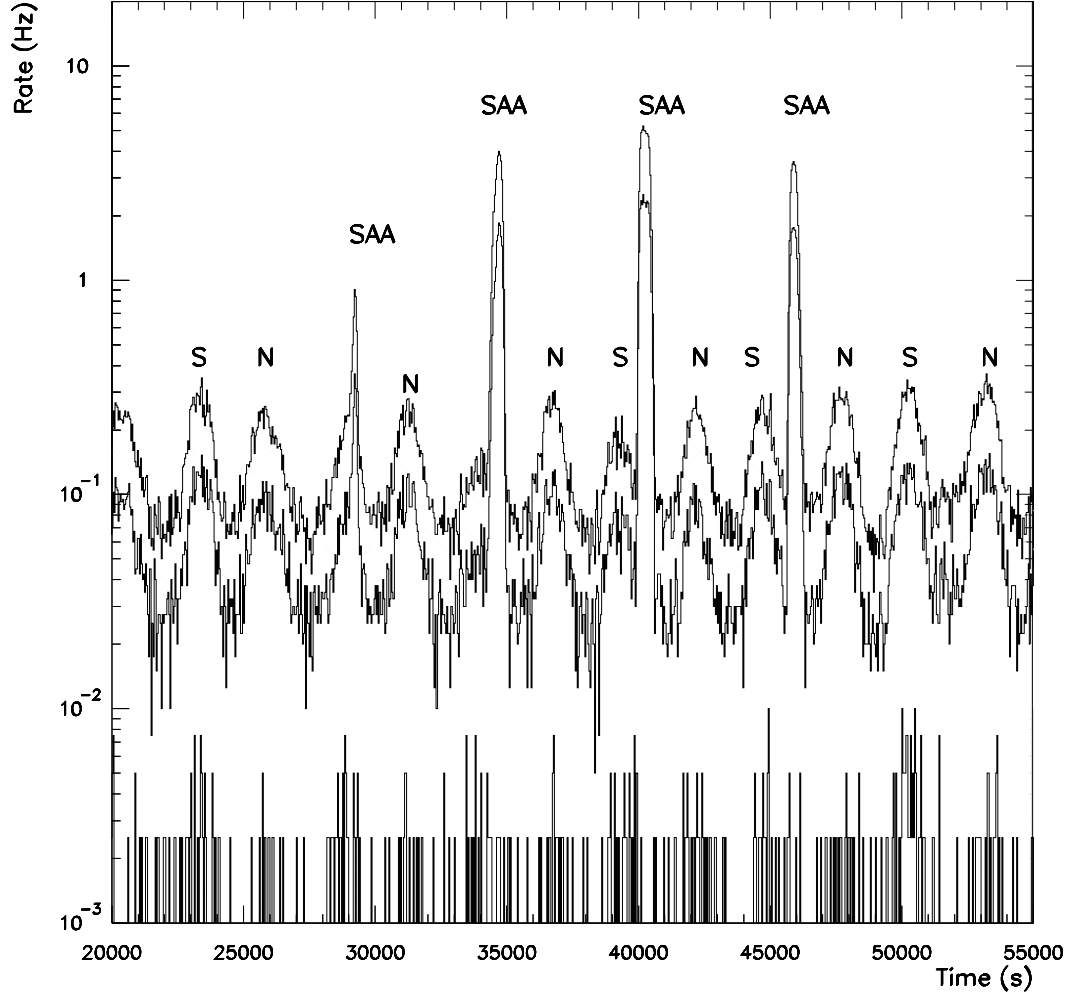


Figure 4. Particle rate as a function of time for a typical acquisition session. Top line: acquisition rate for all events; Center line: Particle rate of $Z \leq 4$, $E > 40 \text{ MeV}/n$, Bottom line: Particle rate of $Z > 4$, $E > 40 \text{ MeV}/n$. The peaks with rate of about 0.3 Hz correspond to passage in the northern (N) or southern (S) regions; the peaks above 1 Hz correspond to passage in the South Atlantic Anomaly (SAA)

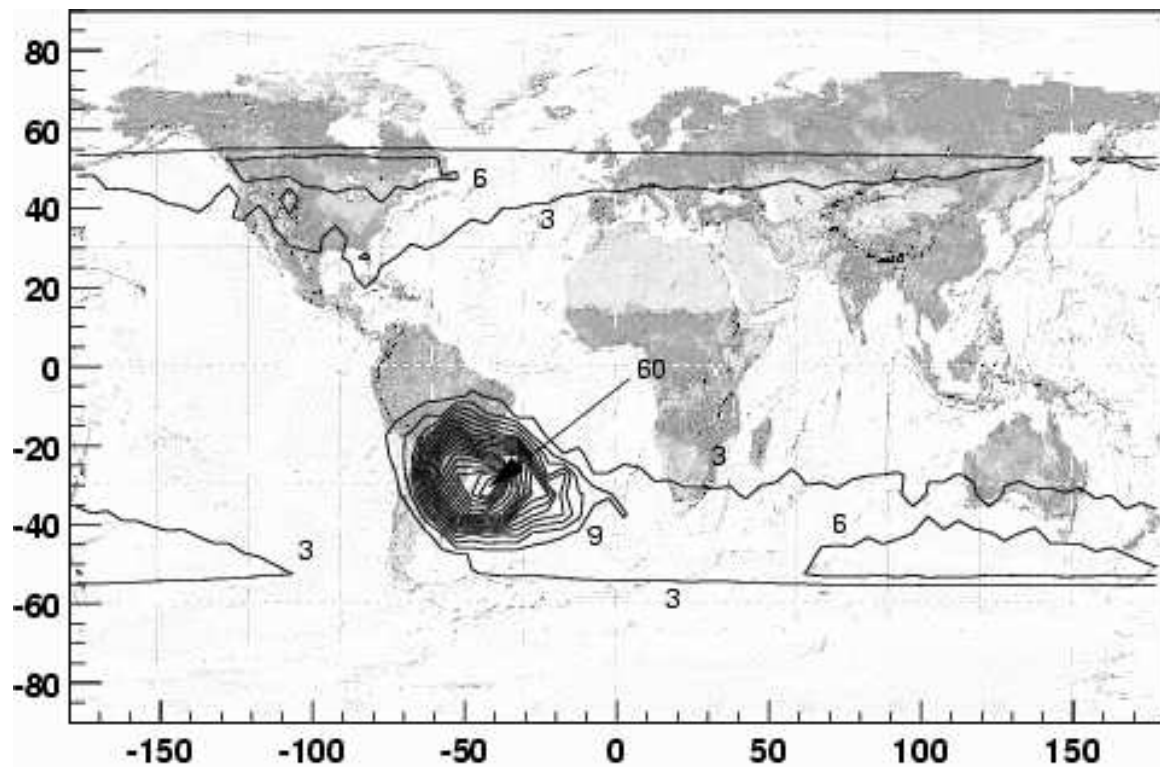


Figure 5. Acquisition rate as a function of position (Y: latitude - degrees, X: longitude - degrees) for all solar quiet sessions. It is possible to see the increase in the SAA region. Each contour level represents a flux increase of 3 Hz.

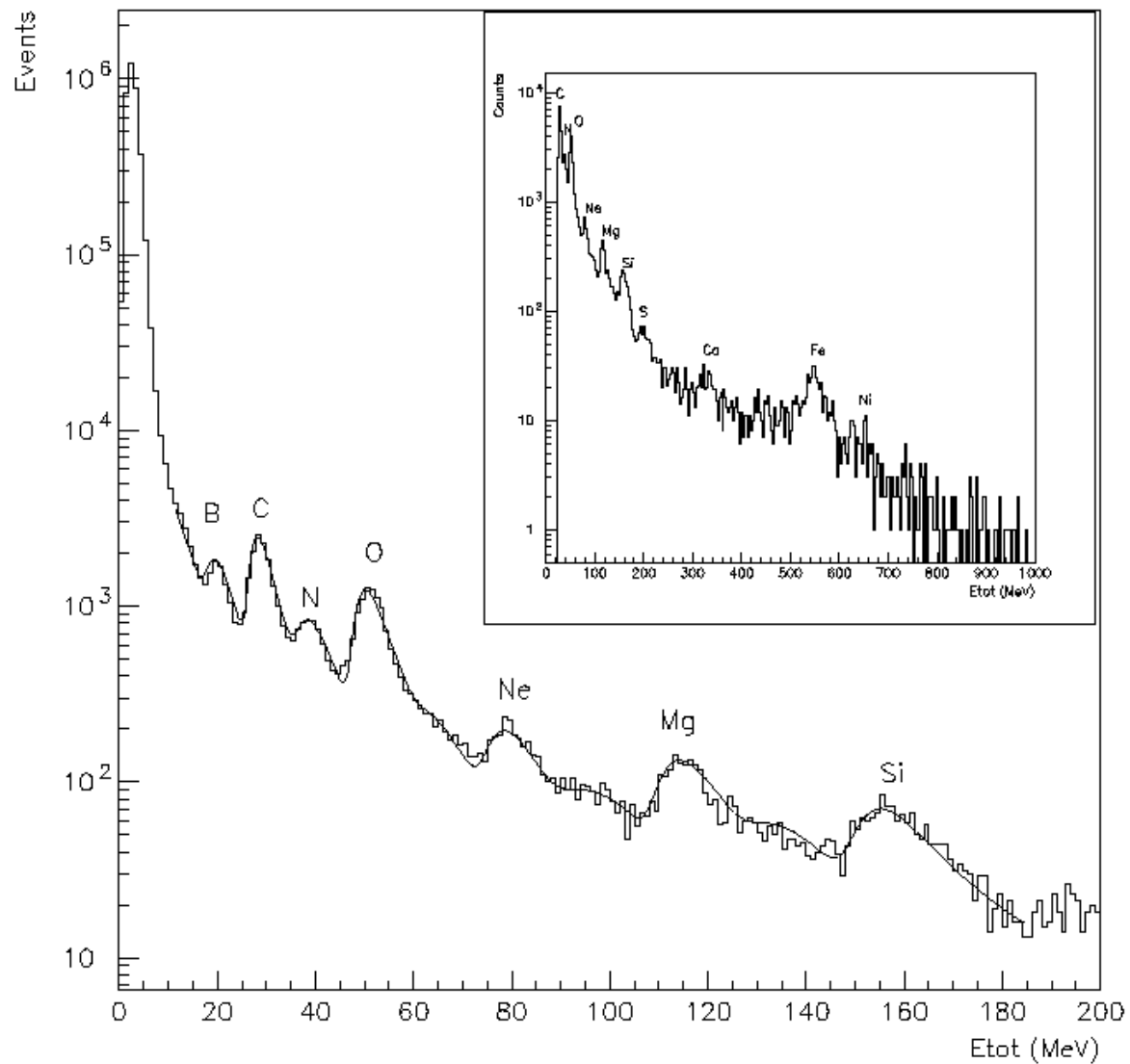


Figure 6. Nuclear identification capabilities of SilEye-2 for nuclei up to Si. In the inset is shown the contribution of nuclei up to Ni. The continuous line corresponds to a fit using a sum of 10 Landau distributions, one per nuclear species (see text).

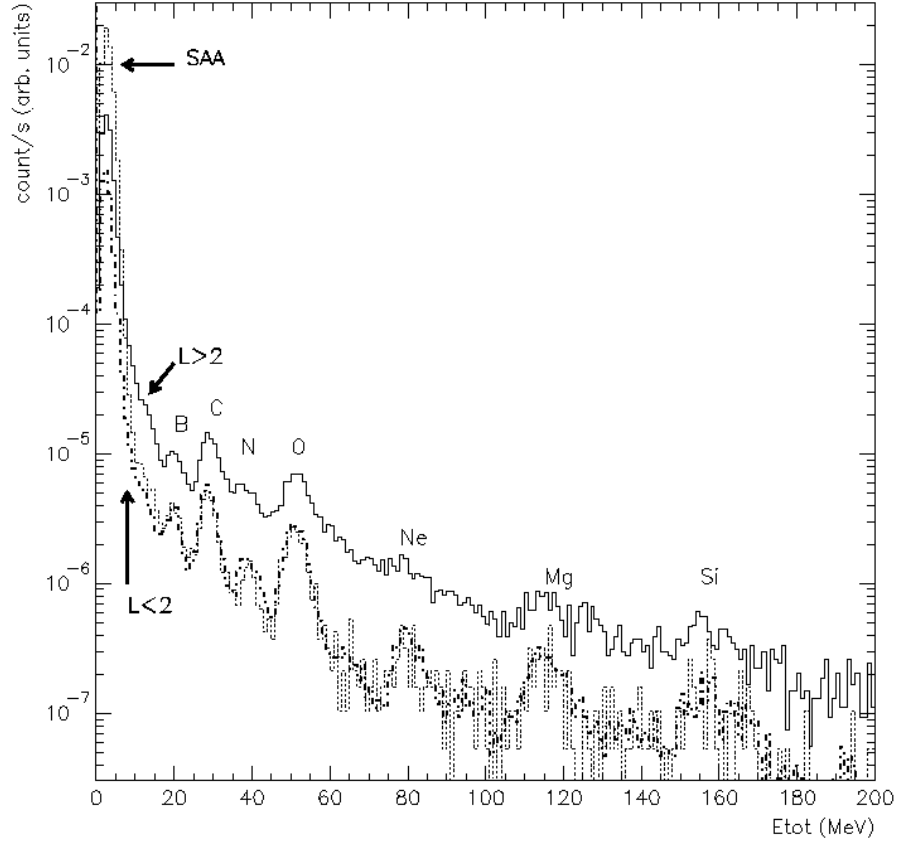


Figure 7. High energy nuclear abundances: Continuous line: galactic ($L > 2$) component; Dotted line: SAA component ($L < 2, B < 0.25G$); Dashed line: remaining region ($L < 2, B \geq 0.25G$). The SAA region has a higher proton flux due to trapped particles but $Z > 5$ particles are equally abundant to the $L < 2$ region due to the equivalent cutoff. In case of the galactic component, the lower geomagnetic cutoff results in a higher integral particle flux so that $Z > 5$ nuclei are more abundant.

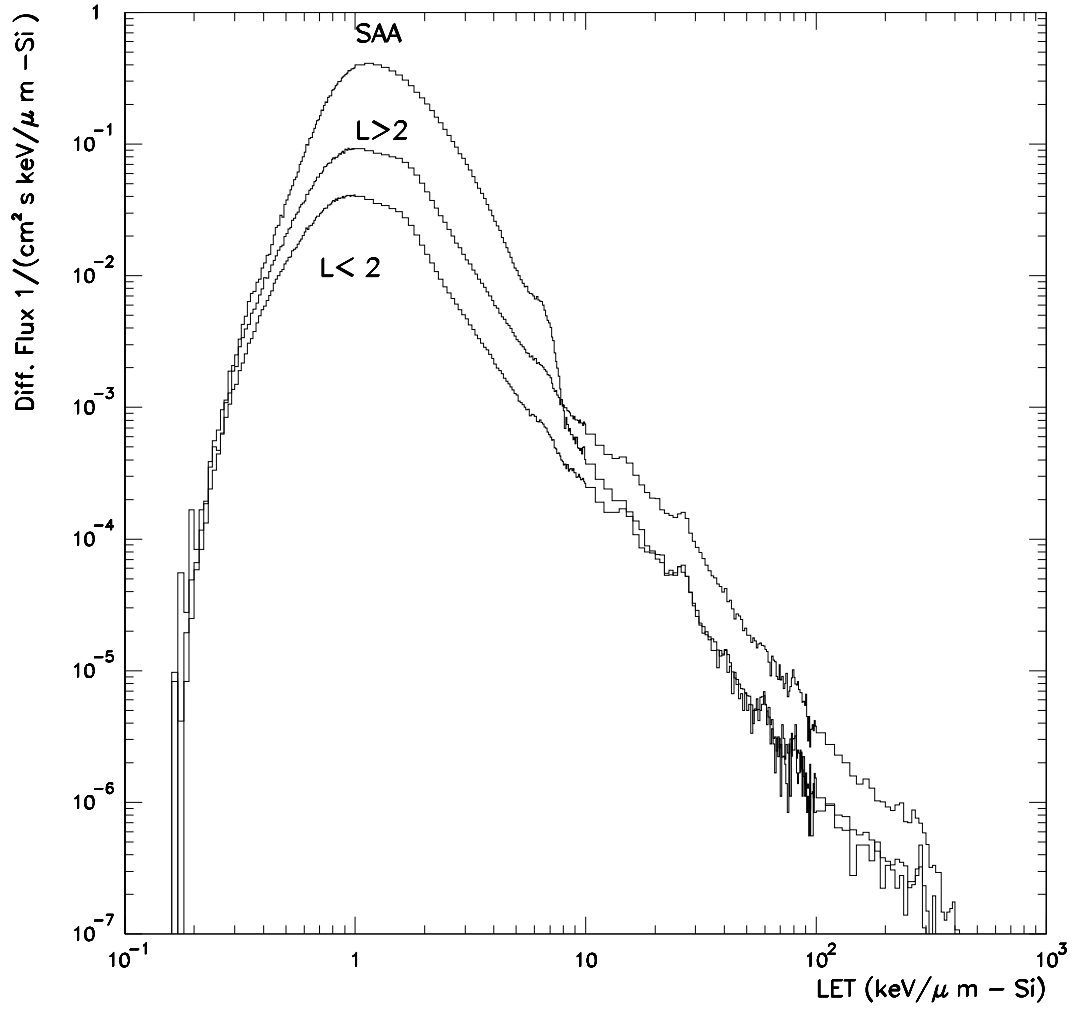


Figure 8. Linear Energy Transfer in silicon for solar quiet period measured with SilEye-2 (solar quiet sessions between August 1998 and August 1999). Top: SAA region. Center: galactic ($L > 2$) region. Bottom: remaining region ($L < 2$, outside the SAA).